castings (a mixture of aluminum oxide, silicon oxide, and zirconium oxide) in a position between the source radiation and the turbine-blade alloy specimen. At an x-ray tube voltage of 150 kVp, many of the diffraction spots near the beam stop (small-angle diffraction) remained. The experiment confirms the ability to perform transmission diffraction even through typical casting mold material.

EXPERIMENT 3

A series of heating, melting, and recrystallization experiments were conducted using x-rays to locate the advancing and receding interface between the solidified metal and molten metal. A 22-millimeter-diameter polycrystalline 99.999% aluminum rod was placed in a quartz tube in a furnace. The rod was heated to (652° C.) (near the melting point) and the changing transmission Laue diffraction pattern was observed. The specimen was then cooled and sectioned for analysis.

Another experiment was conducted in which the aluminum rod was melted and resolidified. Real-time x-ray diffraction was employed to follow the progression of the interface between the solidified aluminum and the molten aluminum. The difference between the pattern generated by the high-temperature solid aluminum and the pattern generated by the liquid aluminum was dramatic and unmistakable. The diffraction spots from the solid disappeared as a diffuse ring formed when the aluminum was fully melted.

EXPERIMENT 4

A copper rod was placed in a quartz tube, with a triangular cross-section. The tube was then inserted into a gradient furnace. A 1 millimeter diameter, collimated x-ray beam was directed into the furnace, and a real-time x-ray imager was placed on the opposite side of the furnace. A 6 millimeter thick, 3 millimeter diameter tungsten disk was positioned in the center of the primary x-ray beam emerging from the furnace to act as a beam stop. X-rays diffracted from the copper sample in the furnace passed to the sides of the beam stop and were imaged.

The furnace was manipulated remotely to move it vertically and horizontally. The vertical movement was used to scan the x-ray beam and imager with respect to the liquid/solid copper boundary that was established in the gradient furnace. Horizontal movement across the wedge-shaped copper specimen permitted interrogating different thicknesses.

The temperature of the furnace was raised to melt the copper and then lowered to solidify it. The warming and cooling sequence was repeated several times. As in the aluminum melting experiments, the solid copper produced a diffraction image with bright diffraction spots. When the melting temperature of copper was exceeded, the ordered diffraction pattern disappeared and was replaced by a diffuse ring of x-ray scattering from the molten copper. This experiment validated the sensing method for locating a liquid/solid boundary in a metal sample with physical characteristics (atomic number and density) similar to that of nickel-based alloys.

EXPERIMENT 5

A gallium sample was placed in a container capable of producing a temperature gradient. A temperature controller was connected to the heater to produce a steady-state boundary between the solid gallium (at the top because its density is less than the liquid gallium) and the liquid gallium. The position of the probing x-ray beam was moved into the solid or liquid by a remote positioning fixture. X-ray diffraction images and radiographic images (by removing the collimating apertures in the x-ray beam) were alternatively taken. The density variation between the solid and liquid gallium is great enough to produce a discernable difference in brightness in a radiographic image. The ability to independently determine by radiographic image the position of the liquid/solid boundary (brighter versus darker regions of the radiograph) provided a means for validating the spatial performance of the x-ray imager.

When the x-ray imager sensor was positioned to probe only the solid gallium, bright diffraction spots were observed. In the liquid, the diffuse scattering ring was observed. At intermediate locations between liquid and solid, the diffuse ring and diffraction spots were present, but both with decreased intensity in rough ratio to their relative amounts. The radiographic images produced with the x-ray images validated that the x-ray imager could accurately locate the position of the liquid/solid interface, and verified that the spatial resolution of the diffraction sensor is approximately the size of the source radiation beam at the sample.

EXPERIMENT 6

The x-ray imager was replaced by an energy-sensitive detector (intrinsic germanium). The much higher efficiency of the detector, compared to the imager, required the replacement of the collimating apertures. The 1-millimeter diameter aperture, used in experiments with the x-ray imager, produced too intense a diffracted beam for the germanium detector. A 0.2 millimeter diameter aperture was used. A source-sample distance of 250 millimeters and a sample-detector spacing of 180 millimeters was used for the experiments. The spectra were obtained with an x-ray tube potential of 160 kV and a tube current of 1 mA.

Spectral peaks at approximately 100 keV and 130 keV were produced by x-ray diffraction spots in a solid gallium sample. There were no discernable peaks in the 100–130 keV spectrum recorded when the x-ray diffraction pattern in a liquid gallium specimen was examined. Although the intensity (x-rays per unit area per second) was higher for the diffraction spots, the spots were highly localized. The spectrum for the liquid specimen, in contrast, recorded more counts overall in each energy interval although the peak intensity was lower.

While various embodiments of the present invention have been described in detail, it is apparent that modifications and adaptations of those embodiments will occur to those skilled in the art. However, it is to be expressly understood that such modifications and adaptations are within the scope of the present invention, as set forth in the following claims.

What is claimed is:

1. A method for monitoring an interface between a crystalline phase and an amorphous phase of a material within a container, comprising the steps of:

directing source radiation through at least one wall of a container and into an interface between a portion of a crystalline phase of a material and a portion of an amorphous phase of said material contained in said container to provide diffracted radiation having a first diffraction component with a first spatial radiation distribution associated with said crystalline phase and a second diffraction component with a second spatial radiation distribution associated with said amorphous